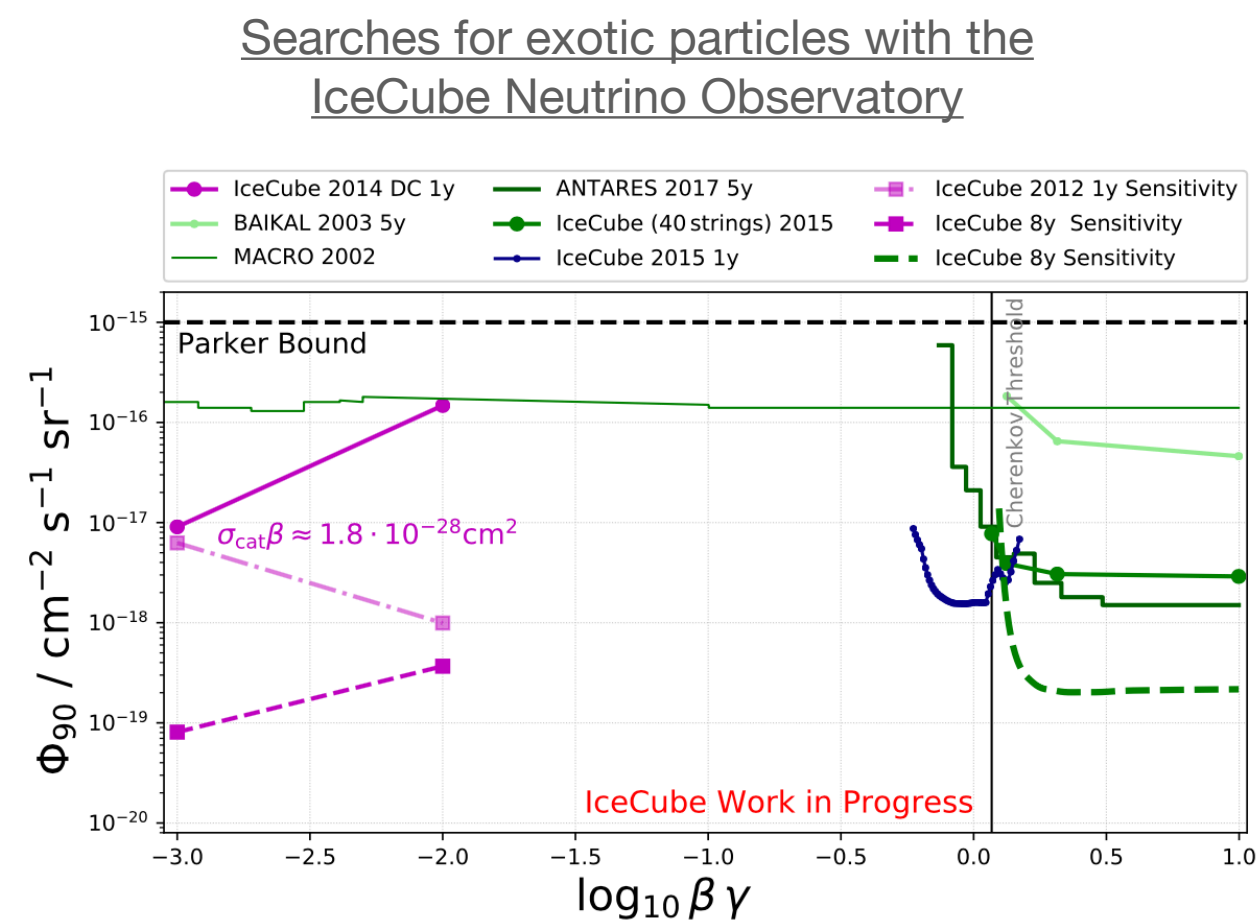
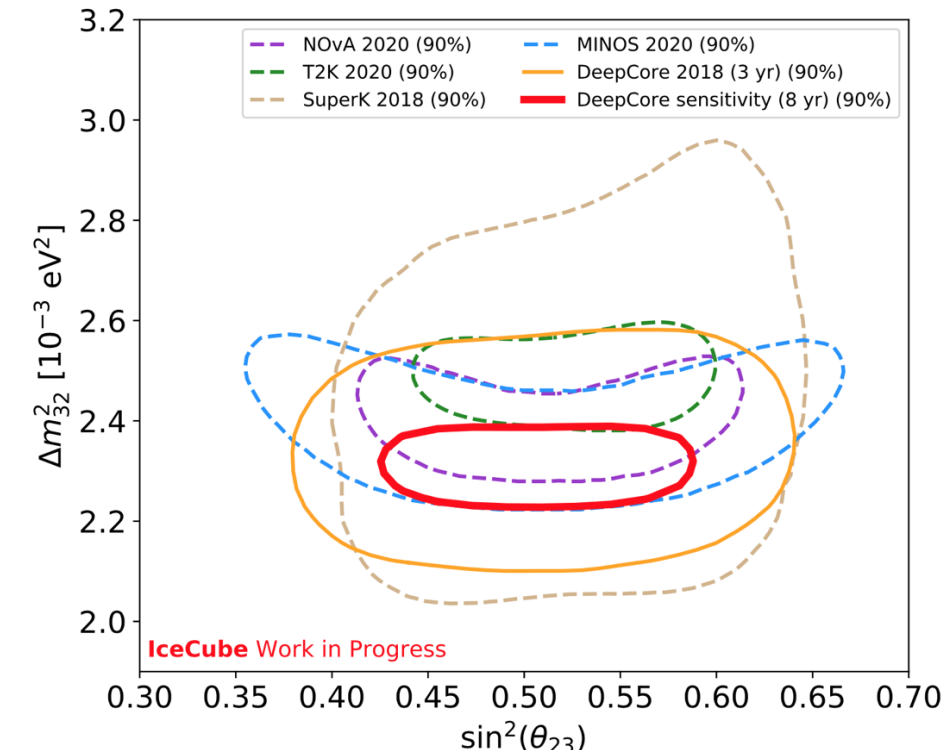


Neutrinos as probes of beyond the Standard Model physics:

IceCube — current and future perspective

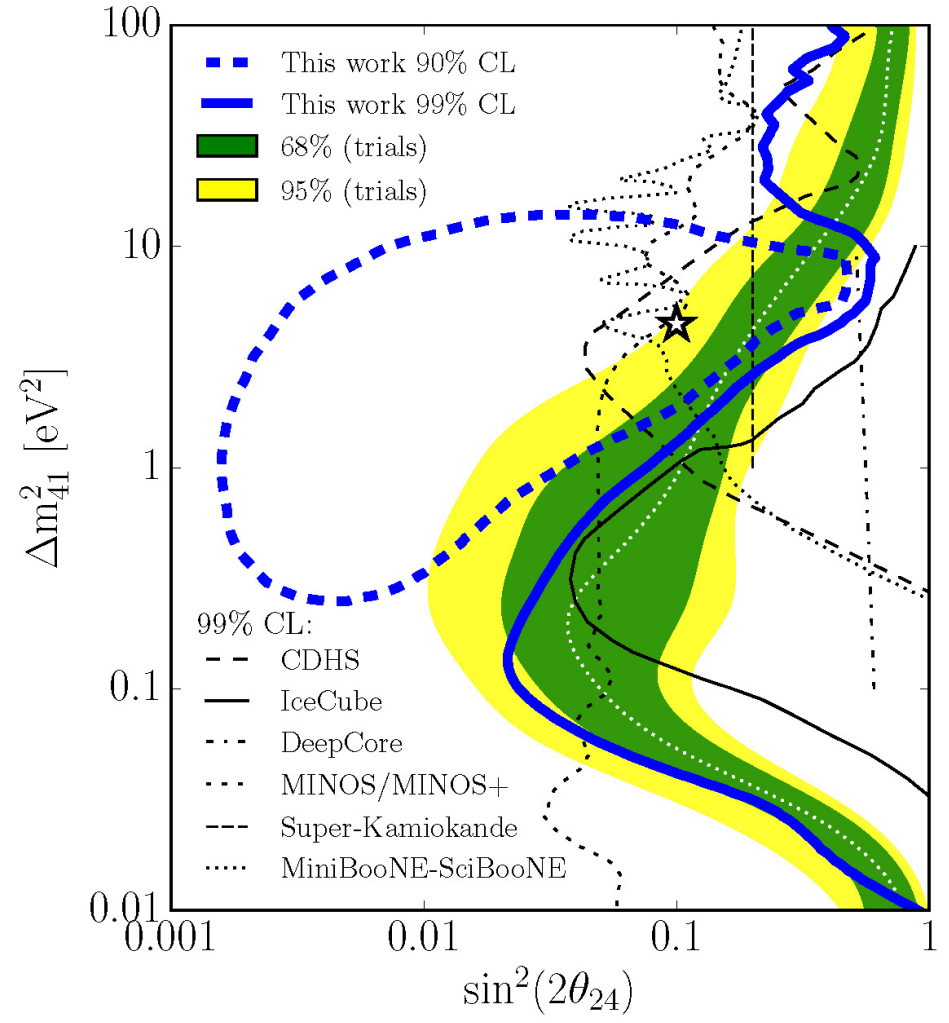


Neutrino oscillations with IceCube-DeepCore and the IceCube Upgrade

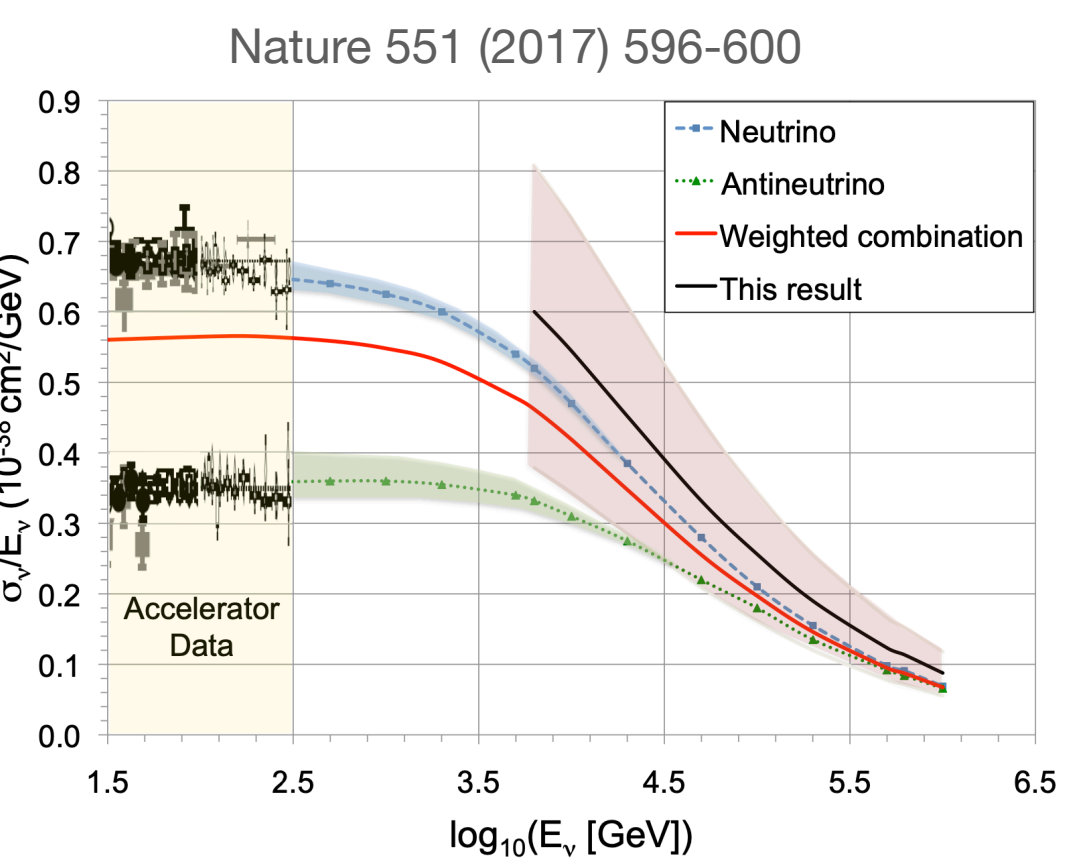


- Very active broad-band studies, including, but not limited to:
- Searches for sterile neutrinos:
 - Including very small active-sterile mixing angle scenarios in supernovae.
 - eV-scale via matter-induced resonance at TeV energies
 - Multi-channel search
 - Neutrino-matter non-standard interactions
 - Neutrino decoherence
 - Standard Model extension of Lorentz violation
 - Unitarity tests of the extended PMNS matrix
 - Neutrino decay
 - Non-oscillation searches for neutral heavy leptons, two-track trident events from Z' , black hole evaporation, extra dimensions, supersymmetry, sphalerons, ALPs, monopoles, **dark matter**...

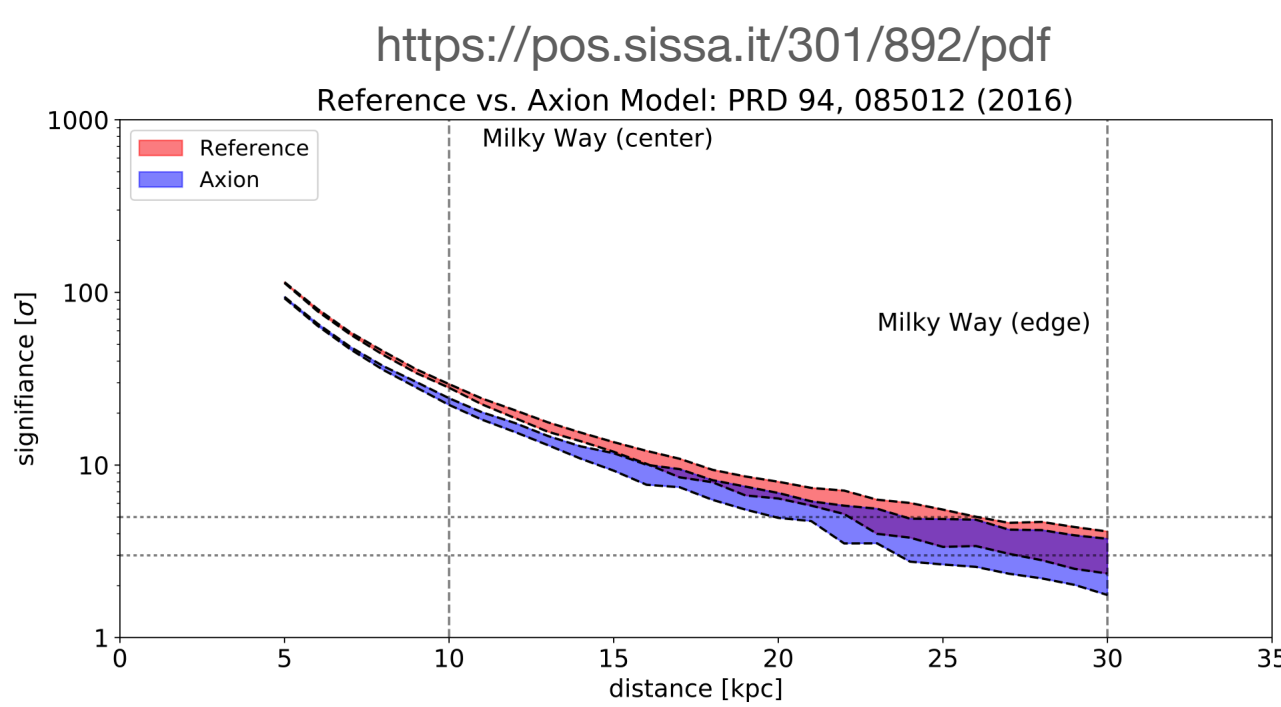
BSM Neutrino Oscillation Searches with 1-100 TeV Atmospheric Neutrinos at IceCube
Phys. Rev. Lett. 125, 141801



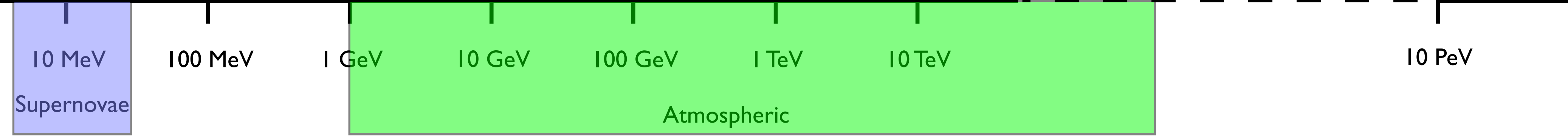
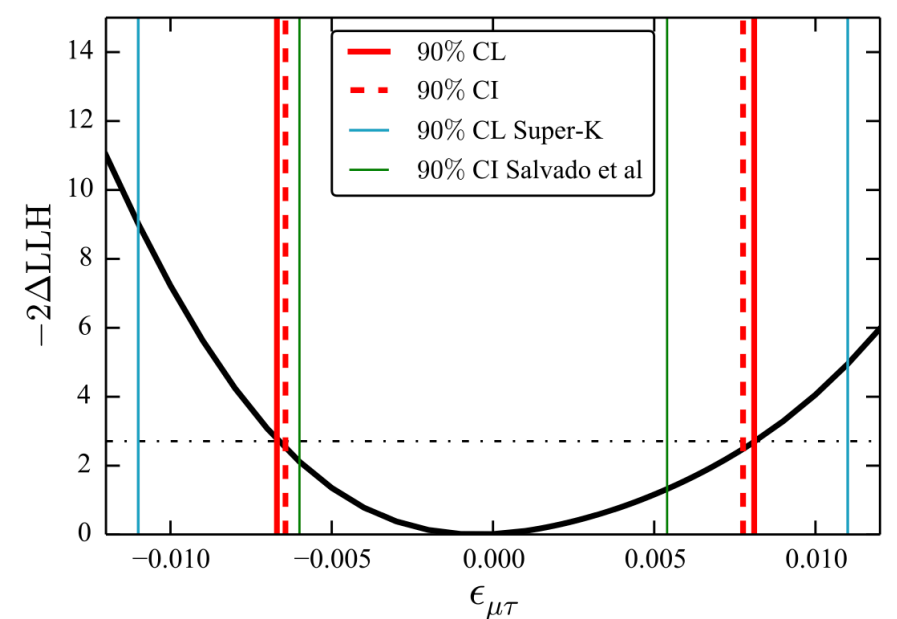
Neutrino cross-sections and interaction physics



Monitoring Galactic core-collapse supernova neutrinos with IceCube and IceCube-Gen2

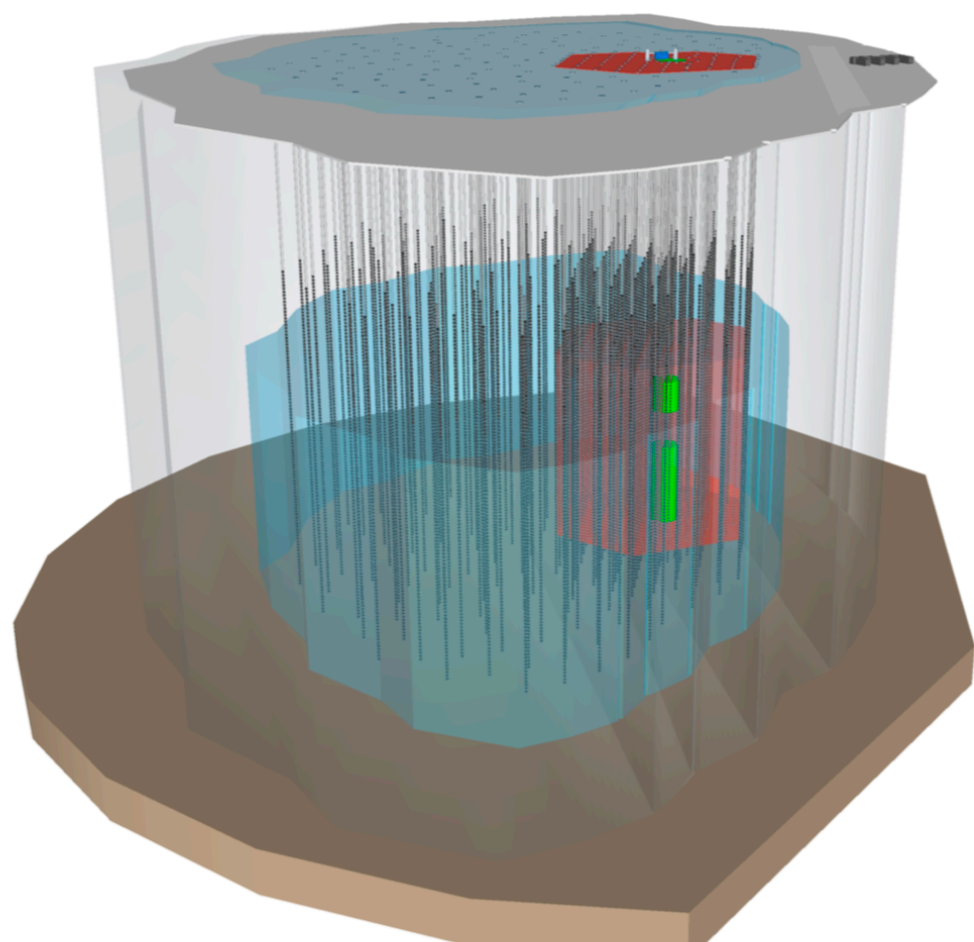


PHYSICAL REVIEW D 97, 072009 (2018)

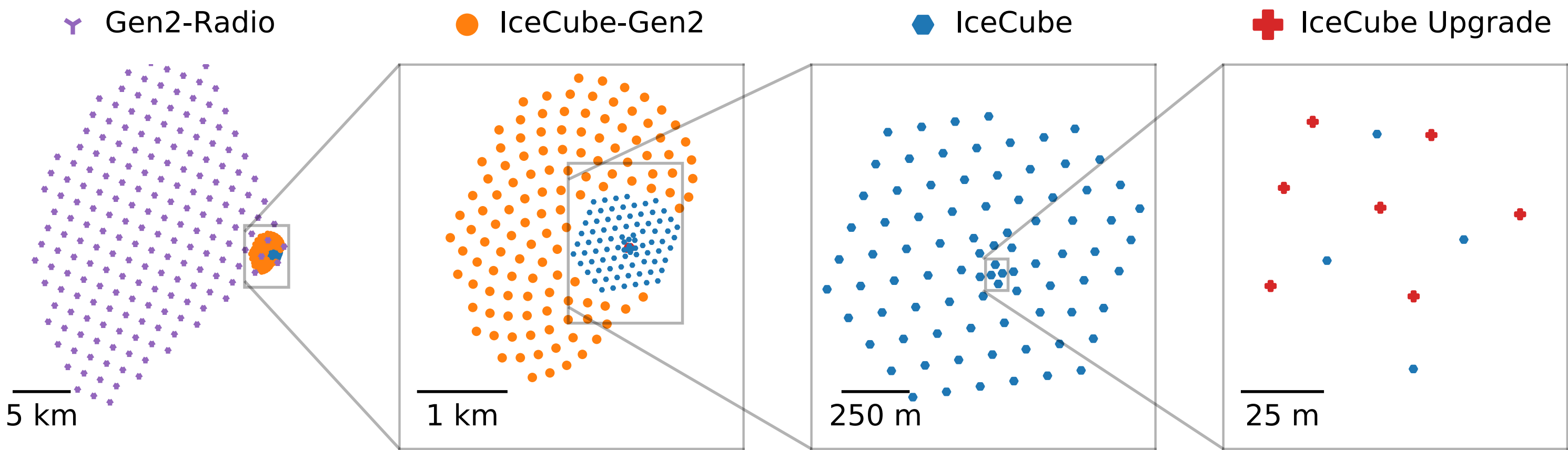


Neutrinos as probes of beyond the Standard Model physics:

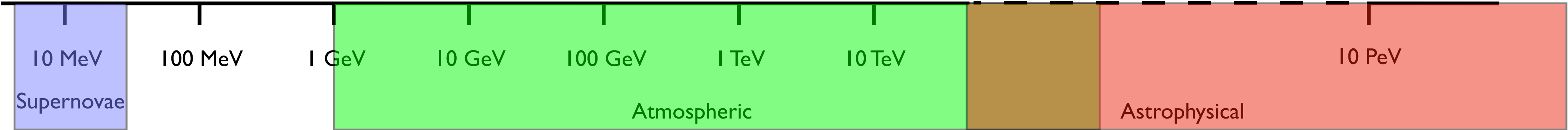
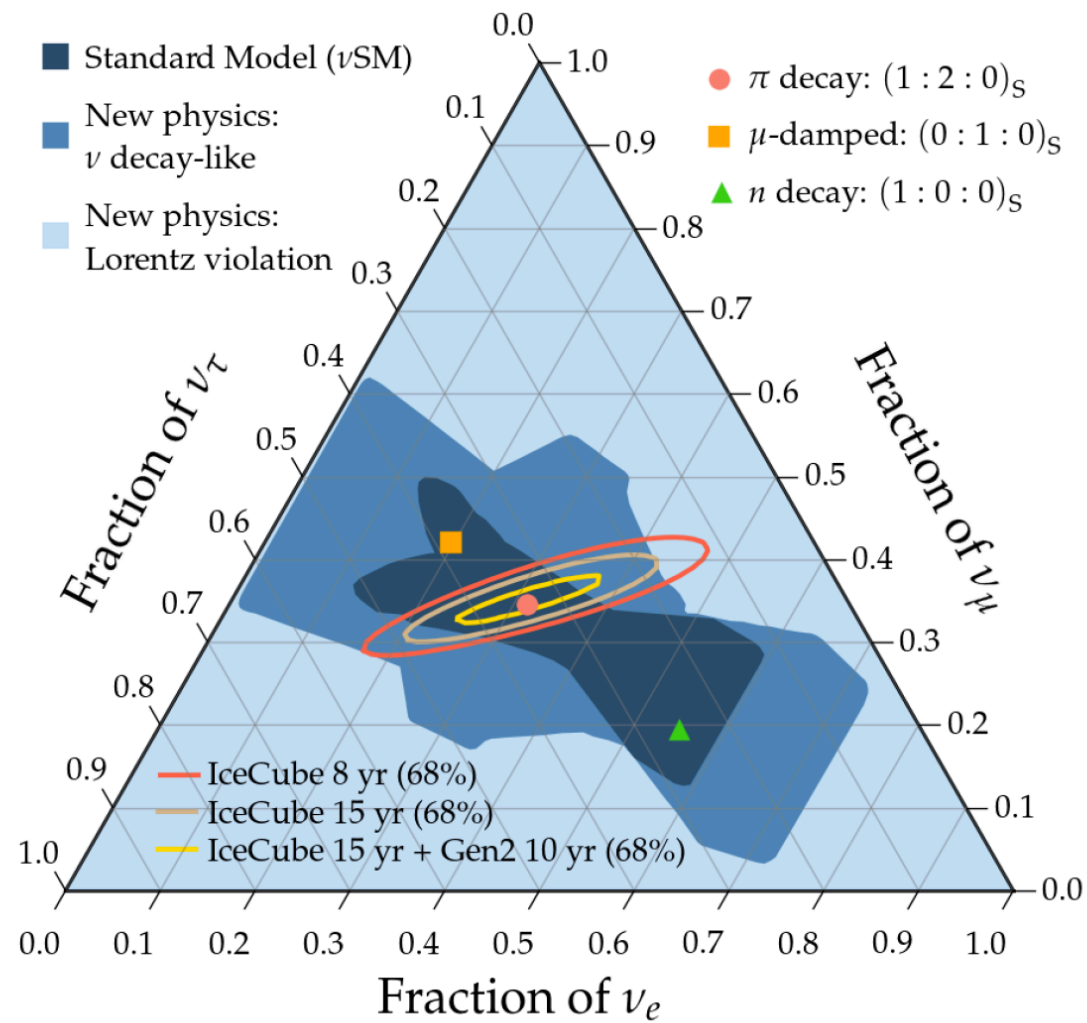
IceCube — current and future perspective



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New physics with astrophysical neutrino flavor



Marco Drewes, Université catholique de Louvain

STERILE NEUTRINO DARK MATTER

06. 09. 2020

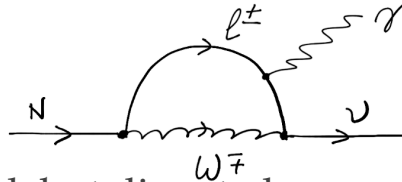
Snowmass Community
Planning Meeting

Session 97 Panel Discussion

Important Aspects of Sterile Neutrino DM

Indirect searches

- radiative decay $N \rightarrow \nu \gamma$ gives **emission line at $M/2$**

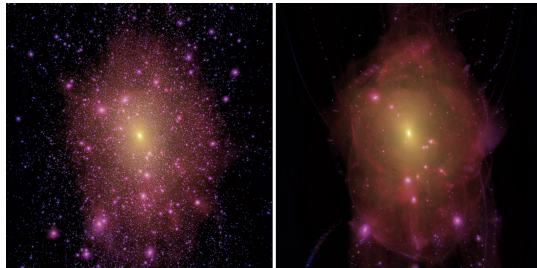


- 3.5 keV excess observed, but disputed
- new missions (XRISM, ATHENA, Lynx...)

Structure formation

Free streaming of DM affects formation of **structures at sub-Mpc lengths**

- matter power spectrum (Lyman α forest, 21 cm astronomy, weak lensing)
- # collapsed structures (dwarf galaxy counts, reionisation history; collapsed objects at high- z)
- matter distribution within collapsed objects
- uncertainties: baryonic feedback, IGM temperature...



Production mechanisms

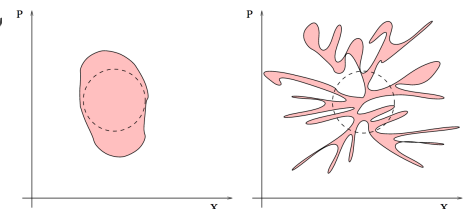
Three known production mechanisms:

- thermal production through mixing-suppressed **weak interaction** (resonant or non-resonant)
- thermal production through **new interactions** at high energies (e.g. gauge interactions in L-R symm. model)
- decay of heavy particle/field** (e.g. inflaton during reheating)

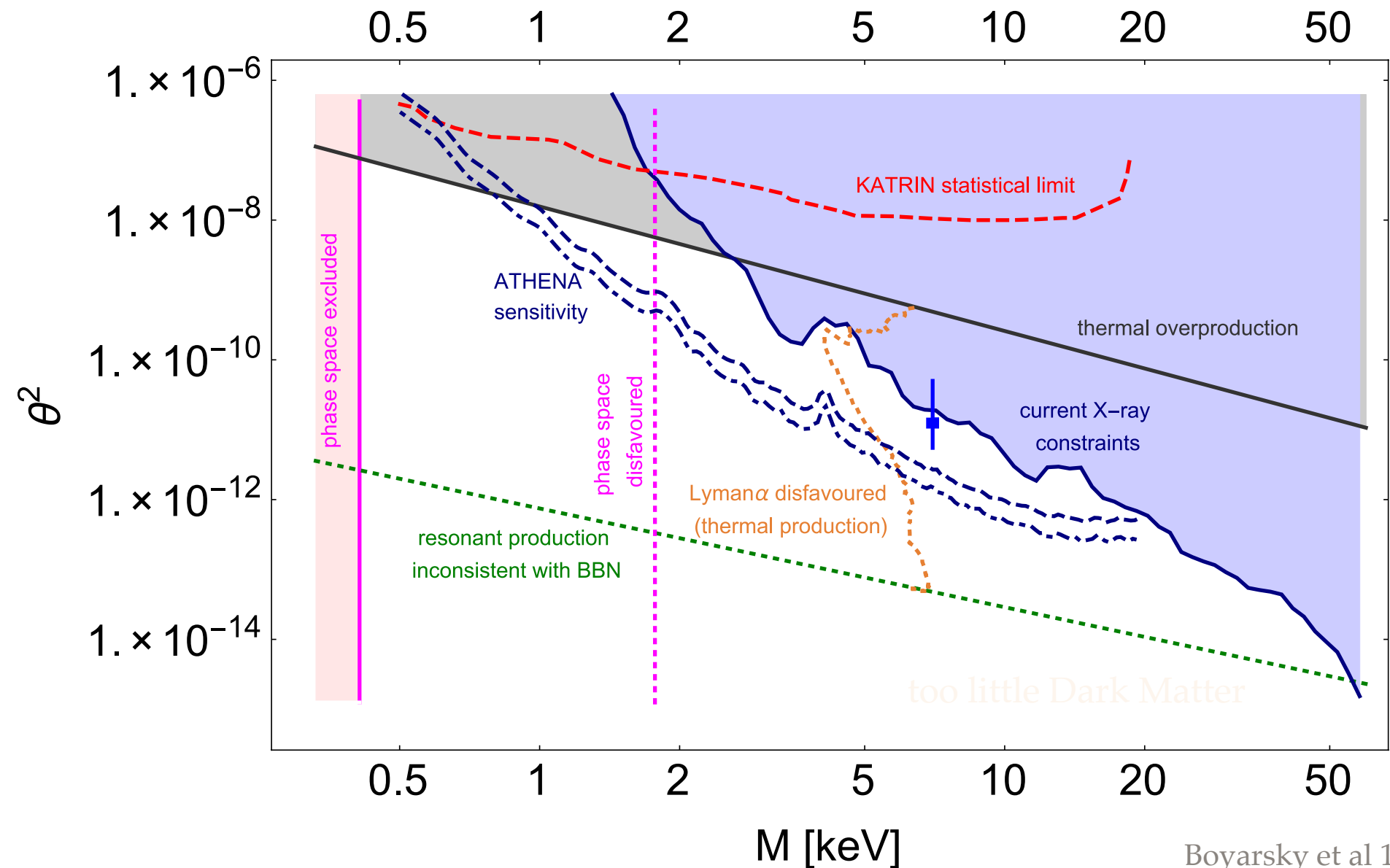
mass	charge	name	mass	charge	name	mass	charge	name	mass	charge	name	spin
2.4 MeV	2/3	u	1.27 GeV	2/3	c	173.2 GeV	2/3	t	0	0	g	1
4.8 MeV	1/3	d	156 MeV	1/3	s	4.2 GeV	1/3	b	0	0	γ	1
0.5 MeV	0	ν_e	0.11 MeV	0	ν_μ	0.106 MeV	0	ν_τ	0	0	Z	0
0.511 MeV	-1	e	105.7 MeV	-1	μ	1.777 GeV	-1	τ	0	0	W	1

Phase space

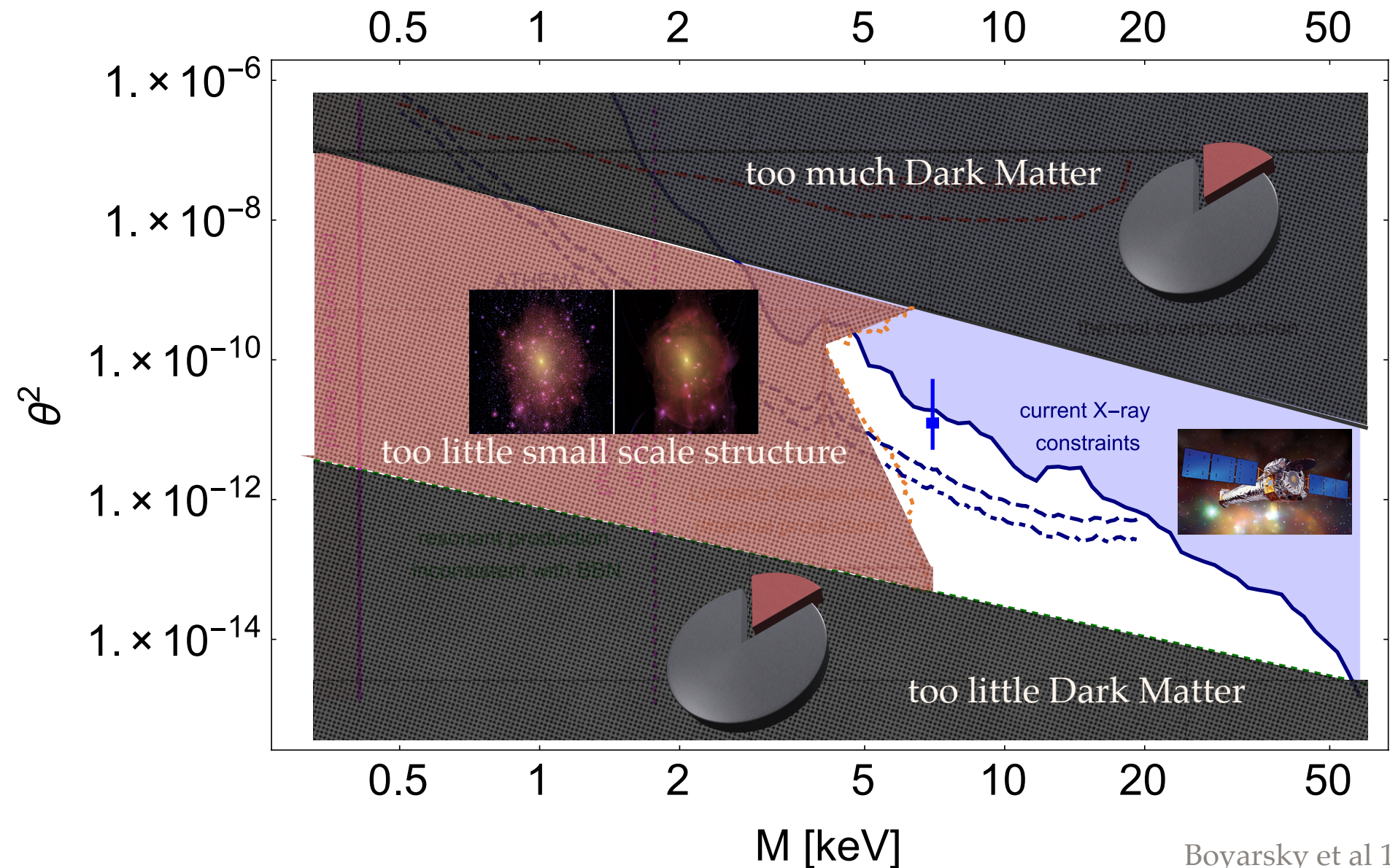
- fermions are subject to Pauli principle
 $M > 25 \text{ eV}$
- applying this throughout the history of the universe yields Tremaine-Gunn bound
- Tremaine-Gunn bound** depends on production mechanism, excludes $M < 0.5 \text{ keV}$ disfavors $M < 2 \text{ keV}$



Constraints on Sterile Neutrino DM



Constraints in the Minimal Model (ν MSSM)



CPM session 97 - Panel 2 - Dark matter aspects

What kind of joint efforts among frontiers/groups/communities/experiment/theory do you envision to progress?

What kind of resources do you need?

What do you envision as the biggest advance in your field in the next 10 years?

Energy - Neutrino - Cosmic - Theory - Accelerators - Instrumentation - Computational

+ Observational astronomy (radio ... TeV)

+ Cosmology

↓
everything solves
(no eternal NOW in DM)

↓
understand/monitor
cosmic laboratories

+ Gravitational Waves

↓
what are
all these
black holes ??

CPM session 97 - Panel 2 - Dark matter aspects

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Agostini, et al. The Pacific Ocean
Neutrino Experiment. Nat Astron
(2020)



<https://www.pacific-neutrino.org>



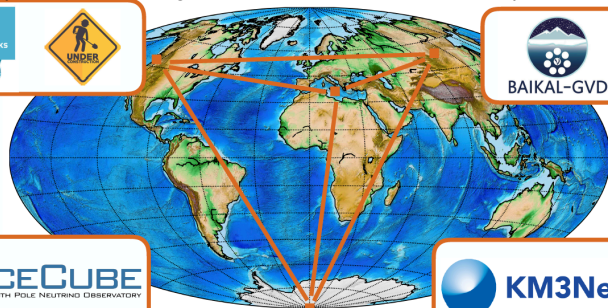
<https://baikalgvd.jinr.ru>



<https://icecube.wisc.edu>



<https://www.km3net.org>

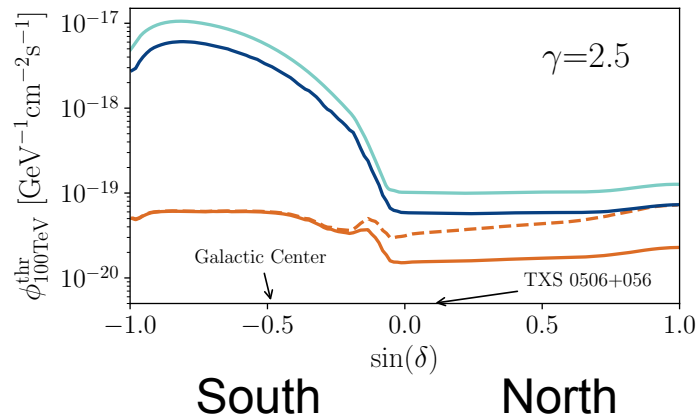


IceCube Coll. IceCube-Gen2: The
Window to the Extreme Universe, Arxiv:
2008.04323



ICECUBE
GEN2

— IceCube(10yr)+PLE ν M \wedge Gen-2(10yr) — IceCube(20yr)
- - - IceCube(10yr)+PLE ν M(10yr) — IceCube(10yr)



CPM session 97 - Panel 2 - Dark matter aspects

What kind of joint efforts among frontiers/groups/communities/experiment/theory do you envision to progress?

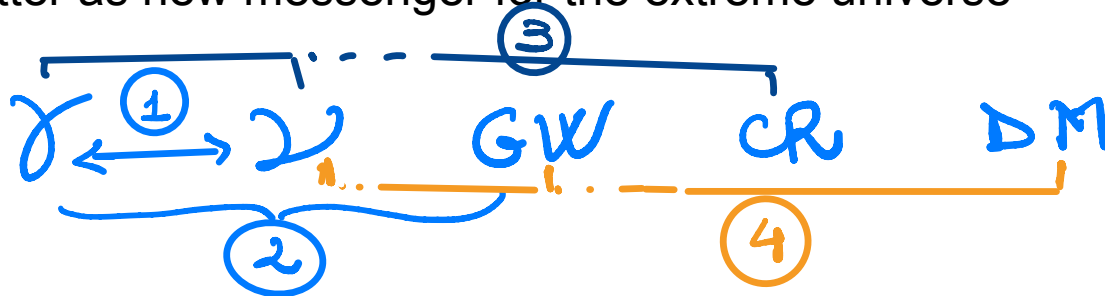
What kind of resources do you need?

What do you envision as the biggest advance in your field in the next 10 years?

From DM discovery to

- IceCube + ANTARES + GVD + P-OE combined
- IceCube stau (long-lived particles)
- Direct searches (underground - accelerators)

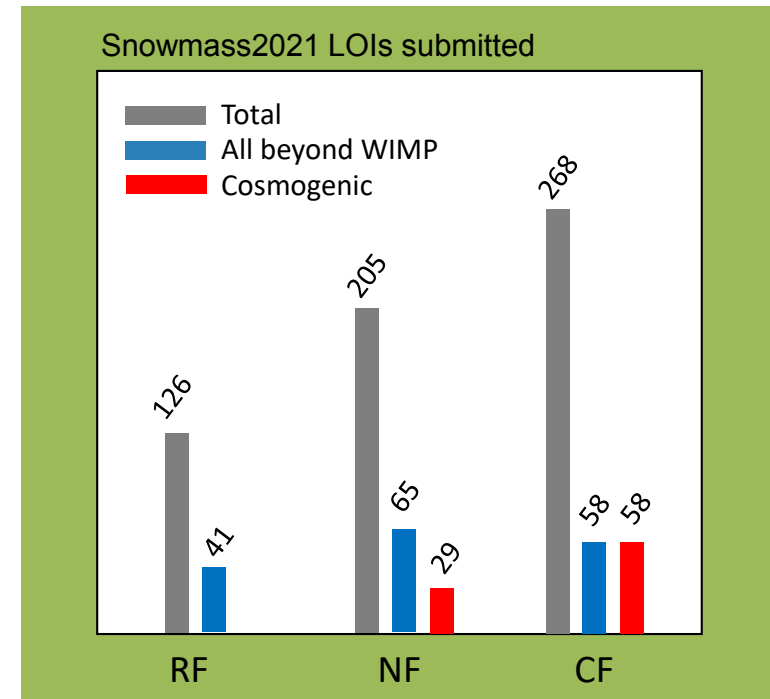
Dark Matter as new messenger for the extreme universe



Biggest advance in the next 10 years?

Understanding and searching for dark sector beyond WIMP

- ✓ No conclusive WIMP signals yet at conventional WIMP detectors
- ✓ Many beyond-WIMP models and scenarios
 - Non-WIMP: MeV-range DM, superlight DM, superheavy DM, etc
 - Non-minimal dark sector scenarios
 - Light mediators/portal particles: ALP, dark photon, etc
 - **Cosmic-origin non-conventional DM signal**: two-component boosted DM scenarios, semi-annihilation, cosmic-ray induced, etc
- ✓ Next-generation experiments commissioning/upcoming
 - High-intensity beam/reactor (neutrino) experiments
 - **Large-volume neutrino and dark matter detectors**



Coexistence: Effort for WIMP continues and new physics opportunities of beyond-WIMP emerges

- ✓ Deepening our understanding of the dark-sector structure
- ✓ Providing “next-to-next-generation” experiments with useful guidance

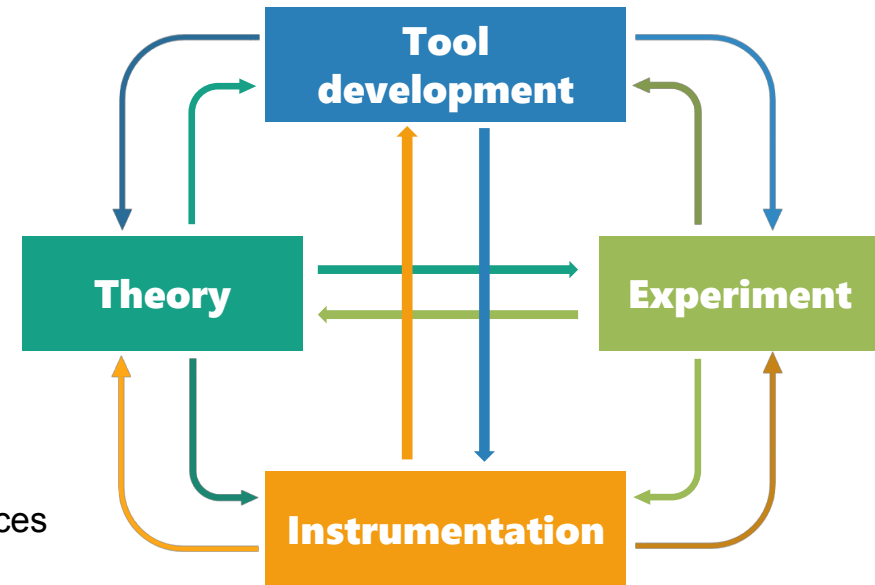
Resources needed and joint efforts to make further progress?

Resources needed

- ✓ Standardized, dedicated, and user-friendly **simulation (e.g., FastSim) tools** for more realistic pheno studies and/or quick estimates (cf. Delphes for LHC pheno)
- ✓ Dedicated **triggering algorithms** especially for cosmogenic signals at large-volume detectors to accept as many signal events as possible

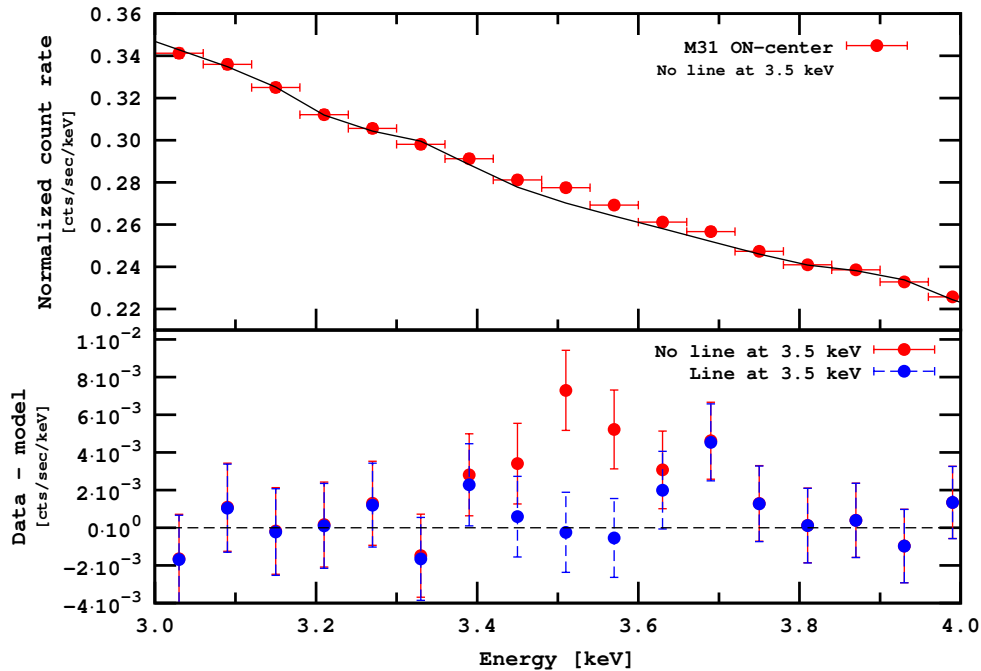
Inter-frontier efforts

- ✓ Theory: new dark-sector models, novel search strategies
- ✓ Experiment: acceptance and efficiency
- ✓ Tool development: machine learning, collaborative simulation development
- ✓ Instrumentation
- ✓ E.g., Periodic workshops where experts from various fields share/exchange their ideas together to acquire the above resources (cf. MC4BSM workshop for LHC pheno)

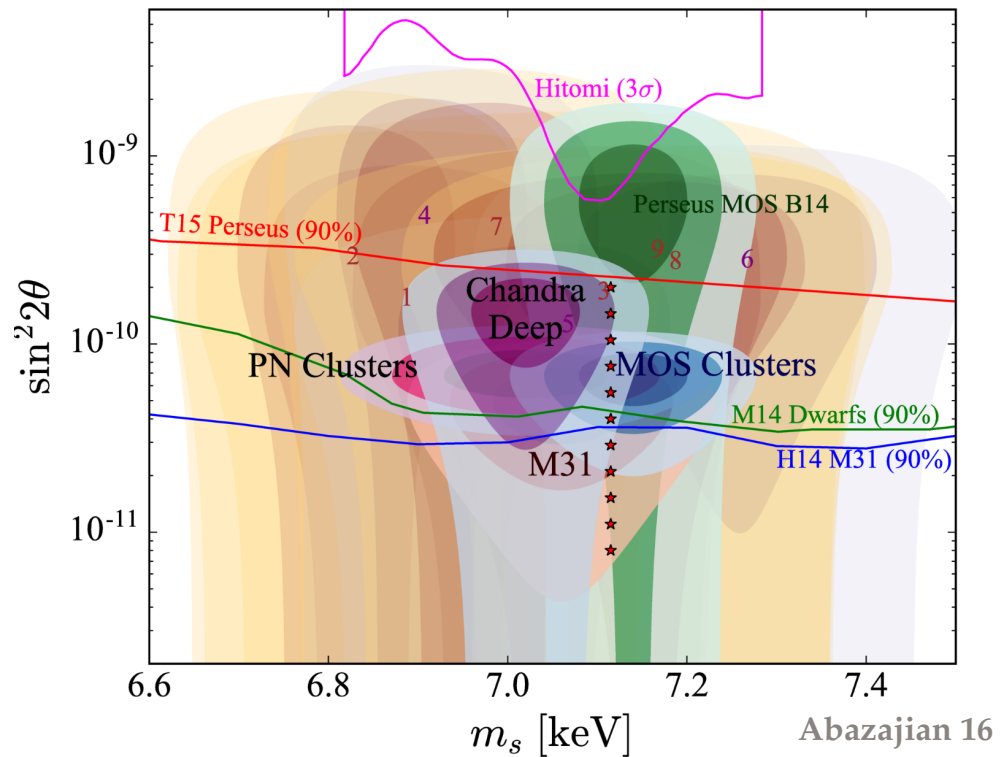


Backup Slides

Has the line been seen?



Boyarsky/Ruchayskiy/Iakubovskyi/Franse 2014
see also Bulbul/Markevitch/Foster/Smith/Loewenstein/Randall 2014



Situation unclear...

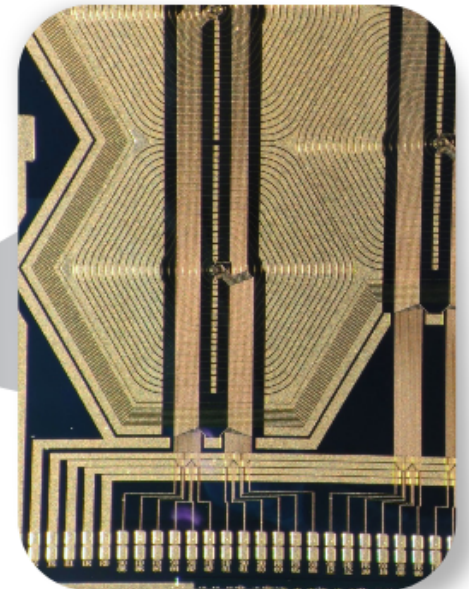
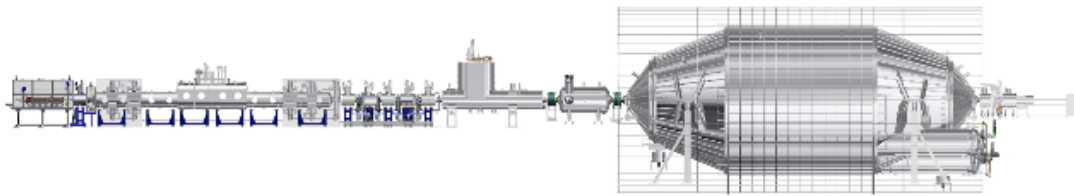
...need better spectral resolution (XRISM, ATHENA+ will help)

Laboratory Dark Matter Search (RF)

Search for sterile neutrinos with a Novel detector system for KATRIN



- 3500-pixel silicon drift detector (SDD) focal plane array
- Excellent performance (noise, resolution, linearity) of first prototypes demonstrated
- Production of first detector module completed
- Integration after KATRIN's nu-mass measurement



Complementarity in the ν MSM

Indirect probes at accelerators
rare decays, EWPD,
lepton universality)

absolute neutrino mass
searches (KATRIN ect.)

non-accelerator
searches
(TRISTAN...)

neutrinoless
double β decay

fixed target experiments
(SHiP, NA62, DUNE,
T2K..)

neutrino oscillation
experiments
DUNE, Hyper-K

new detectors
(FASER, Codex-b,
MATHUSLA, A13X,
ANUBIS

Collider searches for heavy neutrinos

X-ray searches: SRG/eROSITA, SRG/
ART-XC, ATHNEA, XRISM, Lynx...

CMB and LSS :
absolute neutrino mass

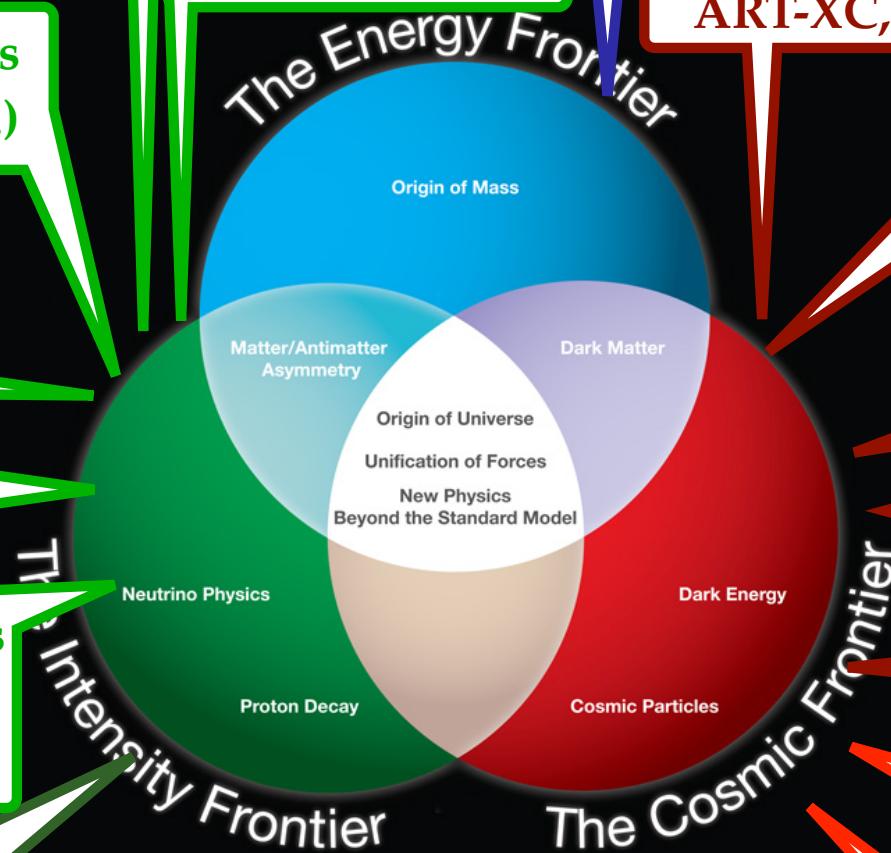
astrophysics:
supernovae etc.

Structure formation:
simulation, observation

IGM temperature:
WDM vs CDM

Theory: leptogenesis
parameter region

Theory: Sterile neutrino
DM production

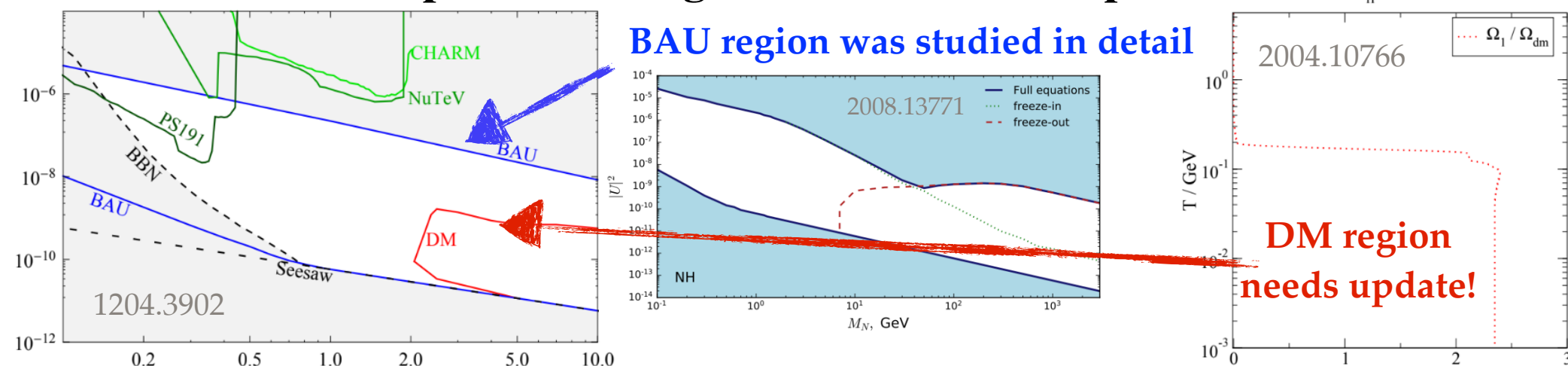


RF, NF, EF, CF, TF

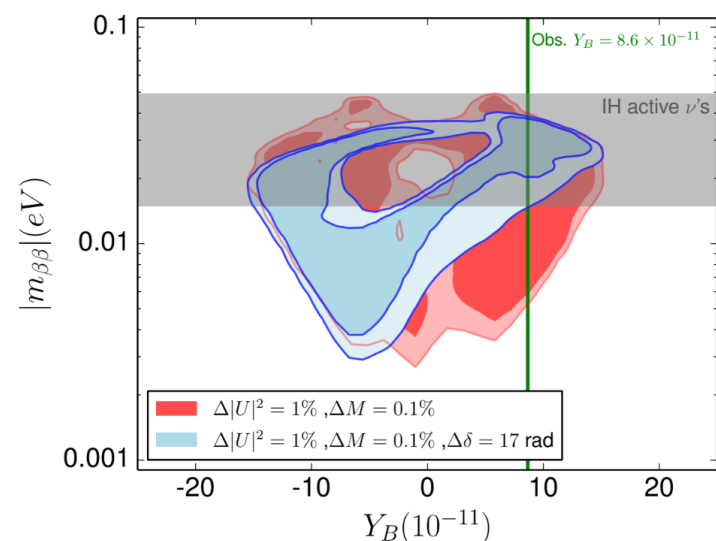
Theory (TF) input for RF

Identification of the parameter region of resonant DM production

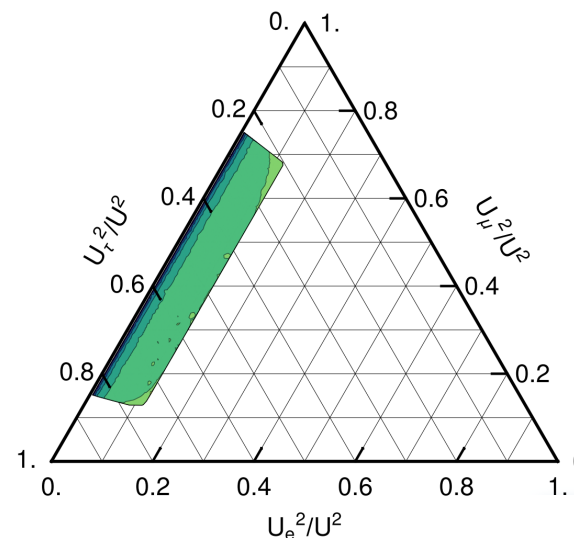
$M_H = 2.0 \text{ GeV}$



Full exploitation of the complementarity of the different “frontiers”



1606.06719



More cross-frontier studies needed!

1710.03744

1609.09069

Heavy Neutrino Searches (RF, EF, AF)

